Wax

PRE-PUBLICATION DRAFT 13 FEB 1975

VARIABLE-LENGTH PACKETS

IN AN UNSLOTTED ALOHA CHANNEL

by

Richard Binder
University of Hawaii
Honolulu, Hawaii

January 1975

Sponsored by
Advanced Research Projects Agency
ARPA Order No. 1956

*****

VARIABLE-LENGTH PACKETS IN AN UNSLOTTED ALOHA CHANNEL

by

Richard Binder
University of Hawaii, Honolulu, Hawaii

Abstract

Some simulation results are presented for an unslotted ALOHA channel when the traffic consists of variable-length packets. The latter consist of 80 bits of overhead, with the number of data bytes approximately geometrically distributed between one and eighty. The packet delay, number of users, and channel thruput are found as a function of the mean retransmission time, and performance compared to that of a channel with constant-length packets. A large range of retransmission mean values are found necessary to optimize the channel (minimize average delay) over the full range of thruput values, for both constant and variable-length packets. Another result is that the maximum number of users can be increased from four to ten times for a mean of ten characters per packet relative to 80-character packets, depending on the desired average delay.

This report was supported by THE ALOHA SYSTEM, a research project at the University of Hawaii, which is supported by the Advanced Research Projects Agency of the Department of Defense and monitored by NASA Ames Research Center under Contract No. NAS2-8590.

ACKNOWLEDGEMENT

The author is grateful to Rodney Okano, Neil Iwamoto, Lorraine Sakaguchi and Peter Law for their sterling programming in the face of countless trials and tribulations.

VARIABLE-LENGTH PACKETS IN AN UNSLOTTED ALOHA CHANNEL

Table of Contents

		Page
	ABSTRACT	i
	ACKNOWLEDGEMENT	ii
	LIST OF FIGURES AND TABLES	iv
1.	INTRODUCTION	1
2.	SIMULATION DETAILS	2
3.	DELAY VS MEAN RETRANSMISSION TIME (R_e)	3
4.	RESULTS FOR OPTIMUM R_e	7
5.	RELATIVE PERFORMANCE VS ℓ	15
6.	CONCLUSIONS	18
	REFERENCES	10

List of Figures and Tables

Figure		Page
1	AVERAGE DELAY VS R_e, ℓ=10	4
2	AVERAGE DELAY VS R_e, ℓ=20, 40	5
3	AVERAGE DELAY VS R_e, ℓ=80 (CONSTANT)	6
4	OPTIMUM R_e VS NUMBER OF USERS	8
5	OPTIMIZED DELAY VS NUMBER OF USERS	9
6	OPTIMIZED DELAY VS THRUPUT	10
7	DELAY HISTOGRAM: ℓ=10, N=250	11
8	DELAY HISTOGRAM: ℓ=10, N=400	12
9	DELAY HISTOGRAM: ℓ=40, N=100	13
10	RELATIVE INCREASE IN NUMBER OF USERS AT S=0.16	16
11	MAXIMUM NUMBER OF USERS VS PACKET LENGTH, CONSTANT DELAY	17

Table		
I	COMPARISON OF DELAY HISTOGRAM PERCENTILES	14

1. INTRODUCTION

This report presents some simulation results for an unslotted ALOHA (random access) channel using variable-length packets. Each packet has a total overhead of 80 bits (sync, header, and parity words), and between one and 80 8-bit data bytes. The number of data bytes in each packet is determined by obtaining a number from a geometric distribution with a lower bound of one; if the number obtained is greater than 80, a value of 80 data bytes is used.

The next section gives details of the simulator used to obtain the data. Graphs of average packet delay as a function of the mean retransmission time are then presented, followed by graphs and histograms of the delay, number of users, and thruput resulting when the retransmission mean is optimized. A subsequent section gives the relative performance improvement which can be expected due to variable-length packets at a high channel loading and under specified delay constraints.

All data was obtained for a 10 Kbps channel data rate and a mean user think-time ("IPT") of 30 seconds. A mean (ℓ) of 10, 20, and 40 characters per packet was used with the geometric length generator, with data also collected for a constant packet length containing 80 characters (720 bits total length). All acknowledgement packets had a constant length of 720 bits. The estimated statistical error of the results is from 5 to 15%, with the larger values occurring for maximum thruput results.

Note: Throughout this report, the term "thruput" will be used to mean the fraction of channel time occupied by successfully transmitted bits, both data and overhead, averaged over periods very long compared to the mean time between packet arrivals in the channel.

2. SIMULATION DETAILS

The simulator consists of a program run on a dedicated Lockheed SUE minicomputer [1]. The communications modelled for each of up to 600 users closely approximates that of a real system -- whenever a new packet is transmitted, the user is prevented from generating another new packet until an acknowledgement is received. Delay is computed for each new packet sent, and is defined as the time elapsing from the start of transmission of the packet to the end of receipt of an acknowledgement.

User 'think-time' is represented by time intervals obtained from an exponential distribution. At the beginning of the simulation, a think-time interval is obtained for each user to represent the start of his first new packet transmission. Subsequently, a new think-time interval is added to the ending time of each acknowledgement packet to obtain the starting time of the next new packet for a user. The same mean think-time is used for all users.

Retransmission intervals are also obtained from an exponential distribution, with the same mean (not necessarily the mean think-time) used for all retransmissions by all users. A constant time equal to the transmission time of two maximum length (720 bit) packets is added to each exponential interval to represent a worst-case waiting time for receipt of an acknowledgement by a user. This total is added to the ending time of the last transmission attempt of a user to obtain the starting time of his next retransmission.

Each simulation run is made for a total of 10,000 packets (new and retransmissions), unless channel saturation occurs; the latter is defined as the case where all simulator packet buffers (approximately 200) have formed a single string of consecutively overlapped packets. The simulator can be restarted at the end of each run using a new seed for the random number generator(s), but with all parameters otherwise unchanged. (A single uniform number generator is used as the basis for all exponential number generations; a second uniform number generator is used to obtain the geometrically distributed numbers for packet length.)

3. DELAY VS MEAN RETRANSMISSION TIME (R_e)

Figure 1 shows the resulting average packet delay for a given number of users as the exponential retransmission mean R_e is varied, with a mean of ℓ=10 characters used for the geometric length distribution. The units of R_e are 720-bit packet transmission times (72 milliseconds at the 10 Kbps data rate). Figure 2 shows corresponding results for ℓ=20 characters (solid curves) and ℓ=40 characters (dashed curves). Figure 3 shows the results when fixed-length 720 bit packets are used. In each set of curves, the number of users is adjusted appropriately to give the same approximate total channel loading.

The left end of all the curves has special significance: if a smaller value of R_e is used for the given conditions, the run almost always results in an 'unstable channel'. This is defined here as either the channel saturation condition described in Section 2 in which over 200 consecutive packet transmissions overlap in time, or a result in which the number of users in a retransmit state continuously increases during the run -- that is, a steady state condition is not achieved after 10,000 packets have been transmitted.

The unstable condition is most pronounced for the smaller values of R_e, e.g., below R_e=20. In this region, a decrease in R_e by approximately 20-30% below the values shown always resulted in the channel saturation condition. As the number of users approaches that for maximum loading (a channel utilization of approximately 1/2e), the unstable condition is not as pronounced. This is reflected in the topmost curves of Figures 1 and 3, where steady state values were also achieved to the left of the minimum delay point on the curves.

A second point of importance is the large variation in optimal values of R_e (corresponding to minimum delay for a given number of users). For R_e=40 in Figure 1, a delay 2 to 5 times greater than the minimum achievable is obtained for 300 users or less, while an unstable condition results for 400 users. Similarly, a value of R_e=70 in Figure 3 results in minimum delay for 100 users, but creates a delay of 1.5 seconds instead of the 0.4 seconds achievable for 40 users (a significant difference for many user environments).

Figure 1. AVERAGE DELAY VS R_e, $\ell = 10$

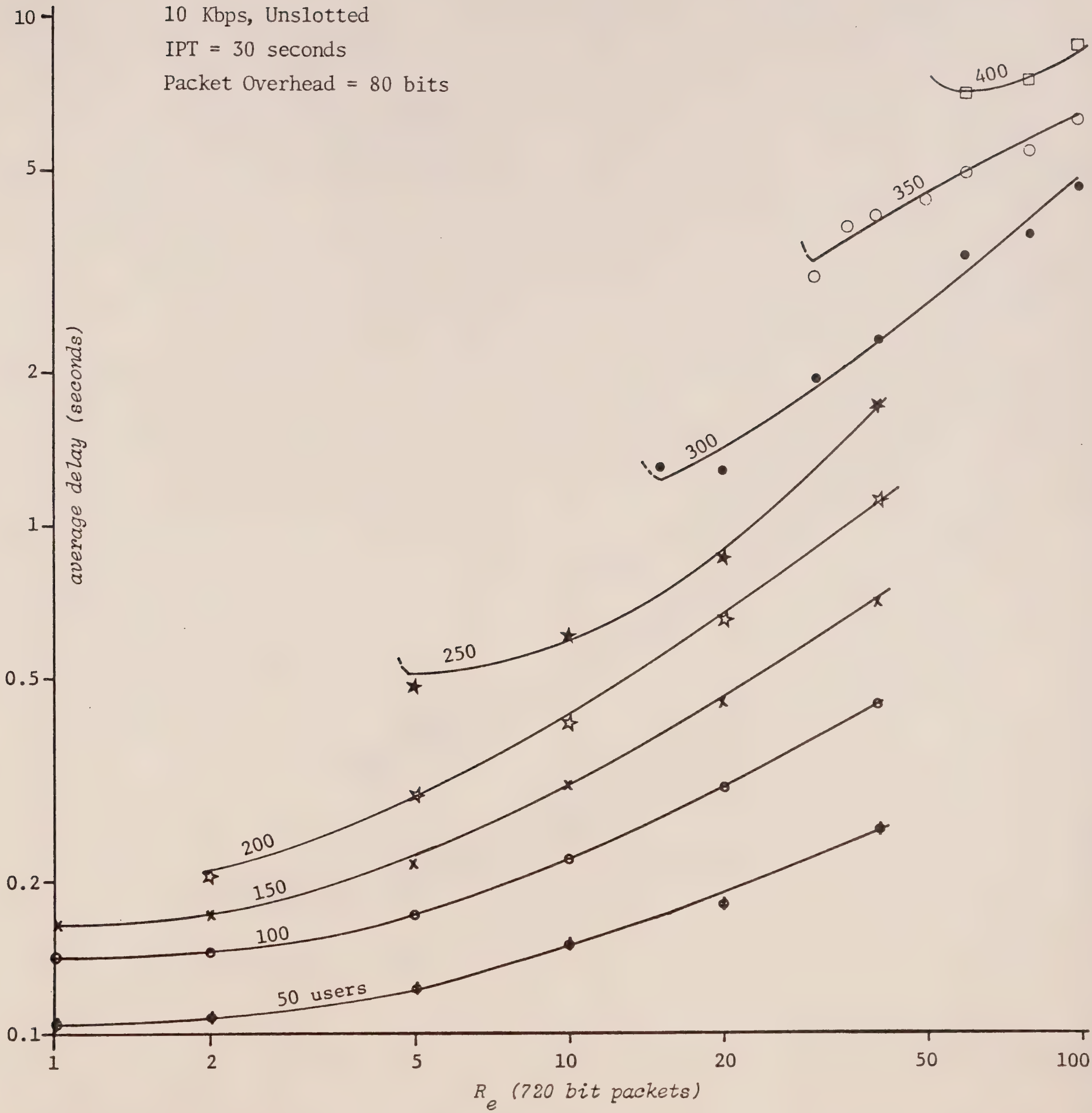


Figure 2. AVERAGE DELAY VS R_e, ℓ = 20, 40

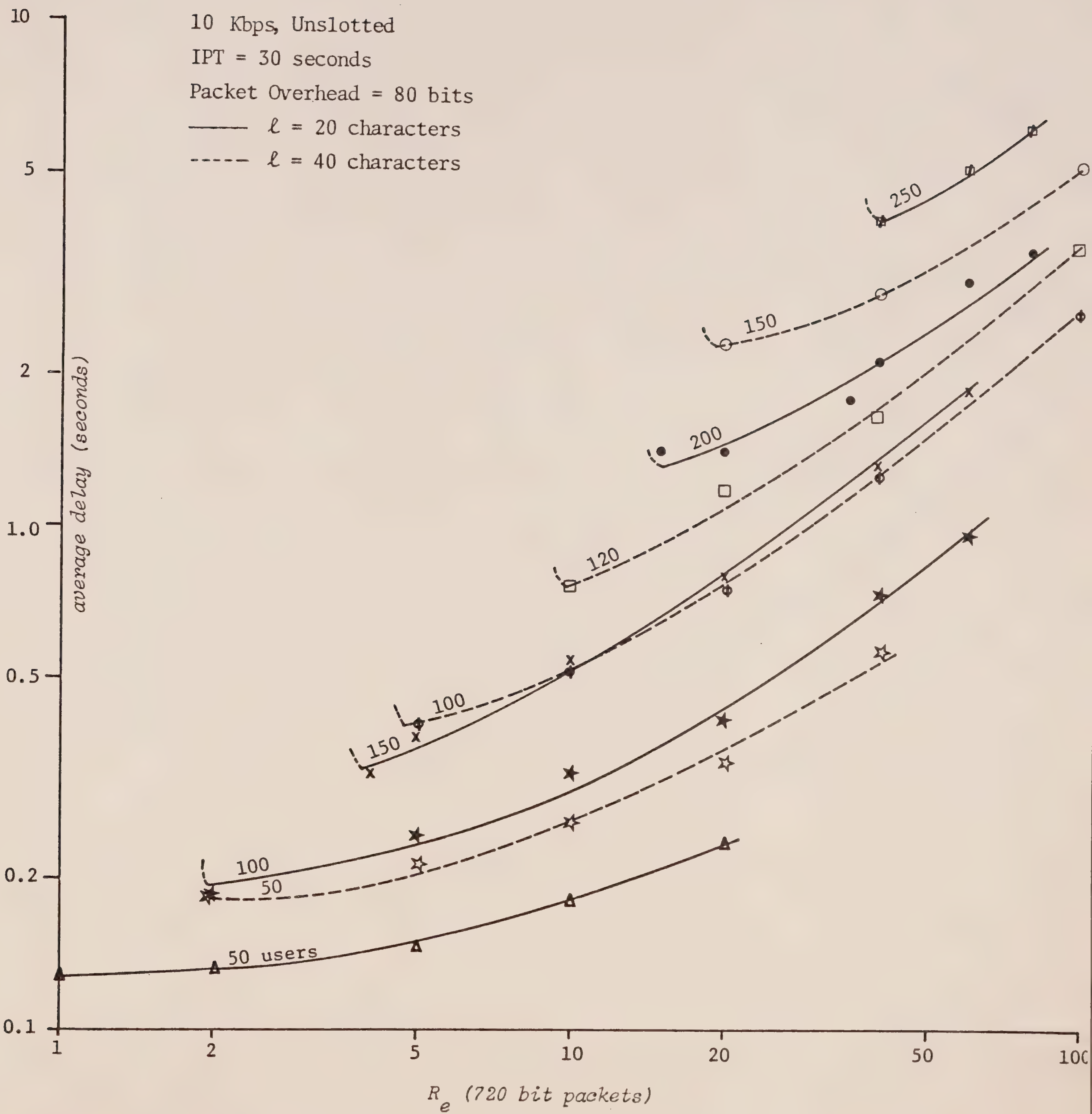
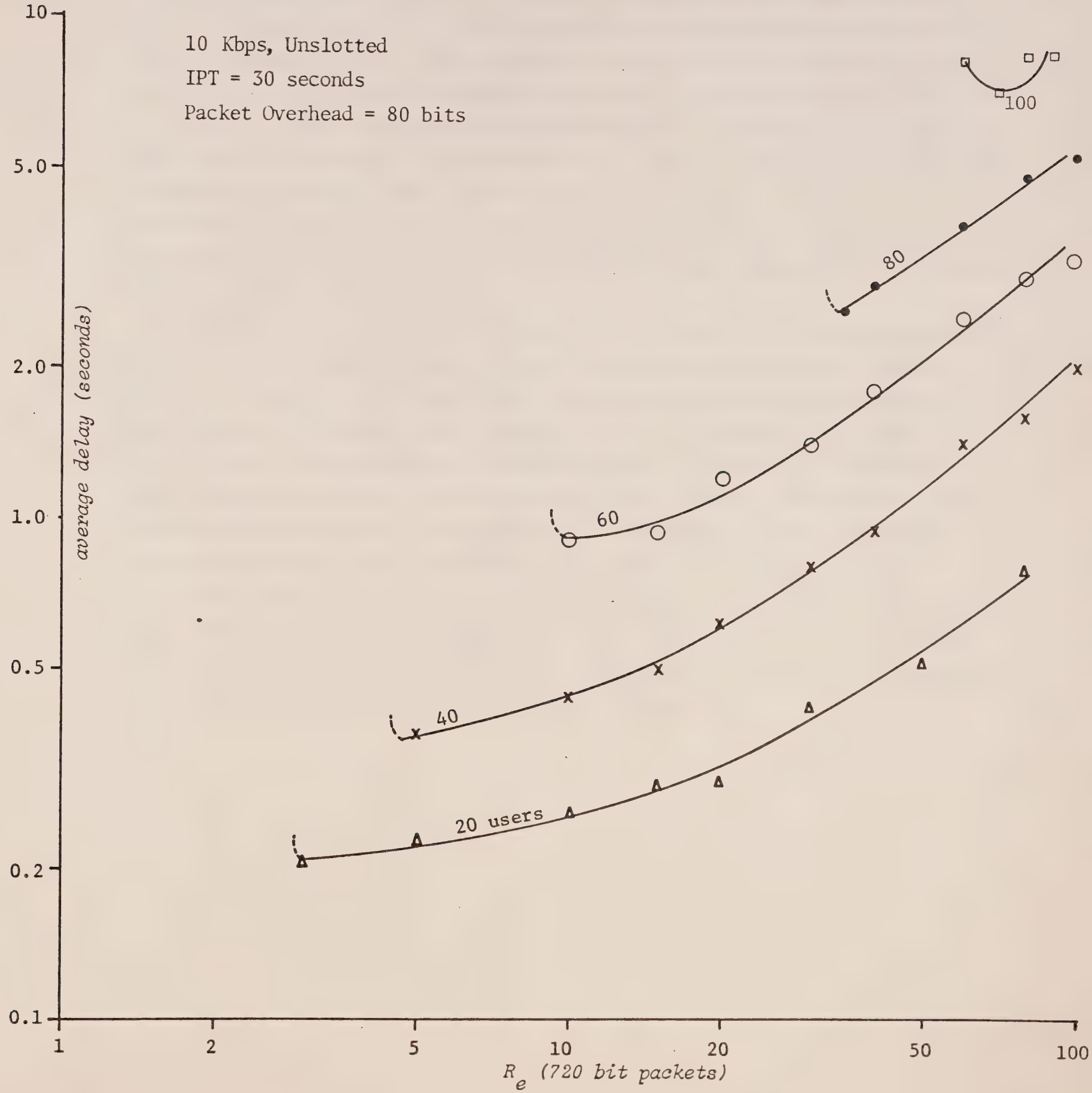


Figure 3. AVERAGE DELAY VS R_e, ℓ = 80 (CONSTANT)



4. RESULTS FOR OPTIMUM R_e

We now focus on the results achievable when the optimum value of R_e is used which minimizes average packet delay for a given set of channel loading parameters (number of users N, IPT, and ℓ). Figure 4 gives these optimum R_e values as a function of N for the different ℓ, obtained from the minimum delay points in Figures 1 to 3. (The rectangular knee of the ℓ=10 curve in Figure 4 is due to the restriction to integer values of R_e in the simulation runs.)

Figure 5 shows the optimized average delay as a function of the number of users for the four packet length conditions. Figure 6 shows the same delay as a function of thruput. Note the crossover of the curves in Figure 6 -- at low values of thruput delay is approximately proportional to mean packet length plus the acknowledgement, while at high thruput values delay is smallest for the constant length packets.

Figures 7, 8 and 9 present histogram data obtained for selected values of ℓ and N. In each figure, packet delay is given in seconds in the leftmost column. In Figure 7, ℓ=10 and N=250, corresponding to an average delay of approximately 0.5 seconds and a thruput of 0.13. In Figure 8, ℓ=10 and N=400, giving an average delay of approximately 8.0 seconds (a relatively large variance was found in average delay values obtained for different runs near maximum loading) and a thruput of 0.17. In Figure 9, ℓ=40 and N=100, for an average delay of approximately 0.5 seconds and a thruput of 0.11.

A comparison of percentiles from each histogram is given in Table I for delay values equal to the mean (m), 2m, and 3m. While there is an increasing trend in the percentages for increased thruput, (S), the results show approximately the same behavior for the different loadings.

Figure 4. OPTIMUM R_e VS NUMBER OF USERS

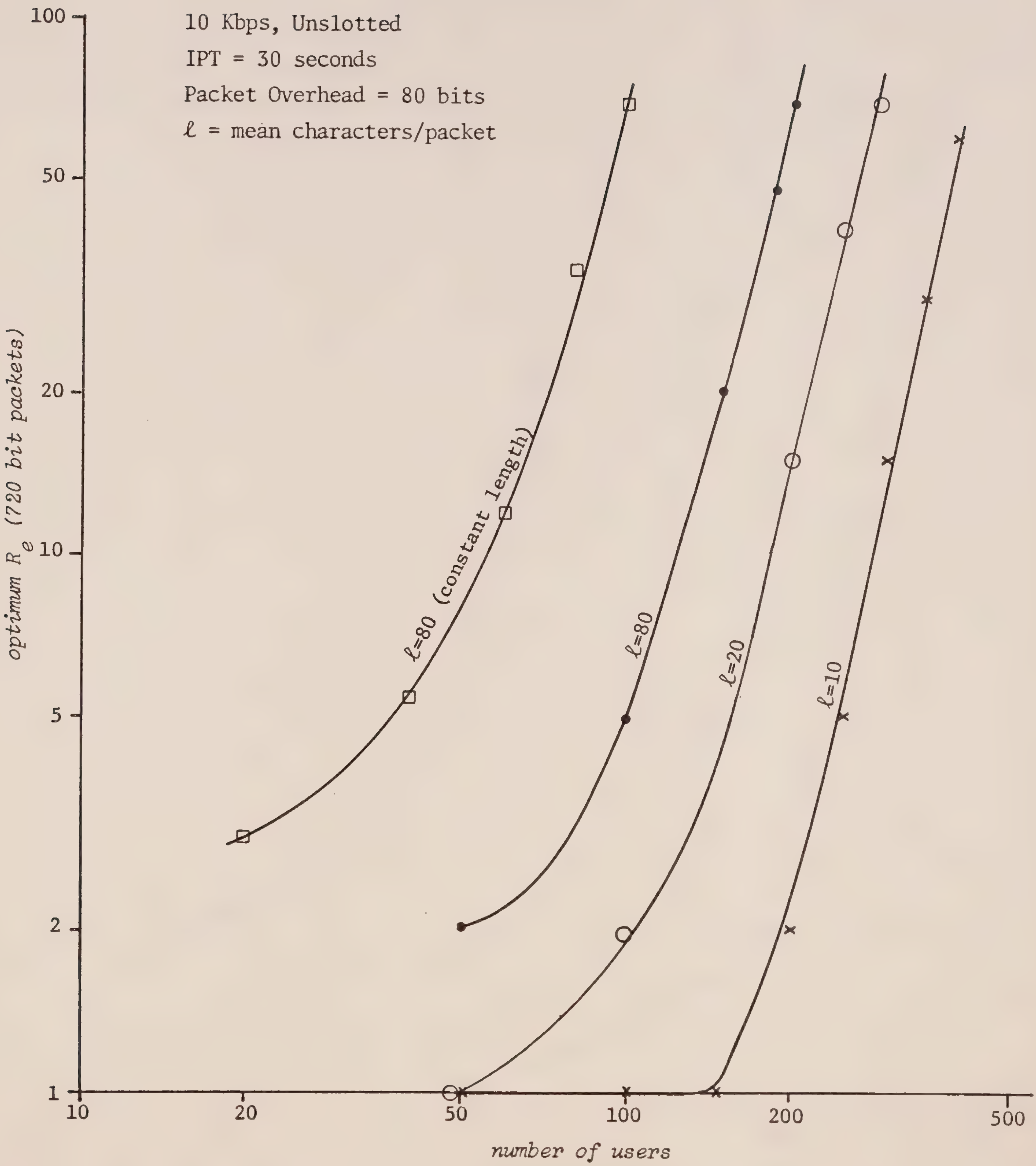
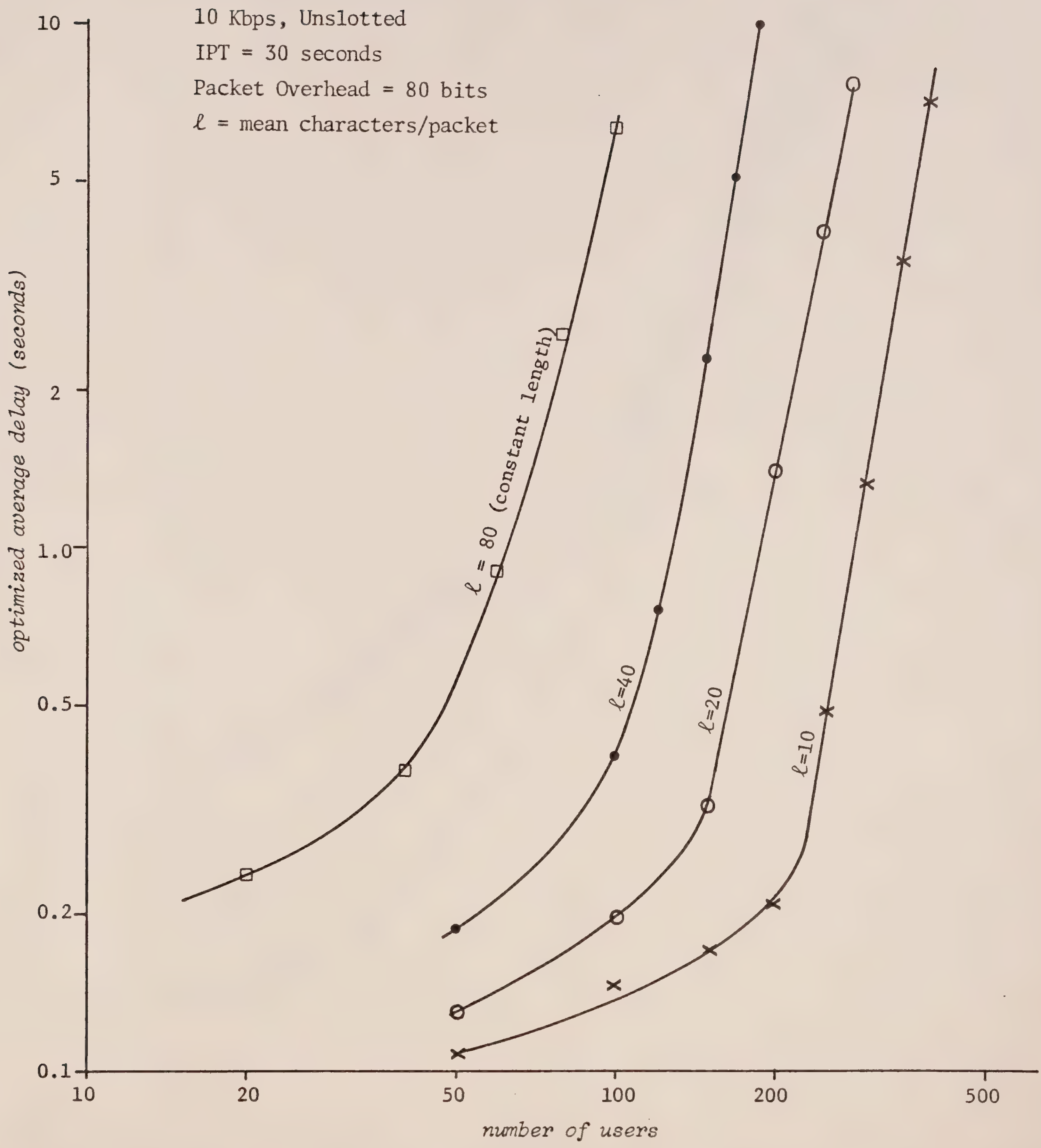


Figure 5. OPTIMIZED DELAY VS NUMBER OF USERS



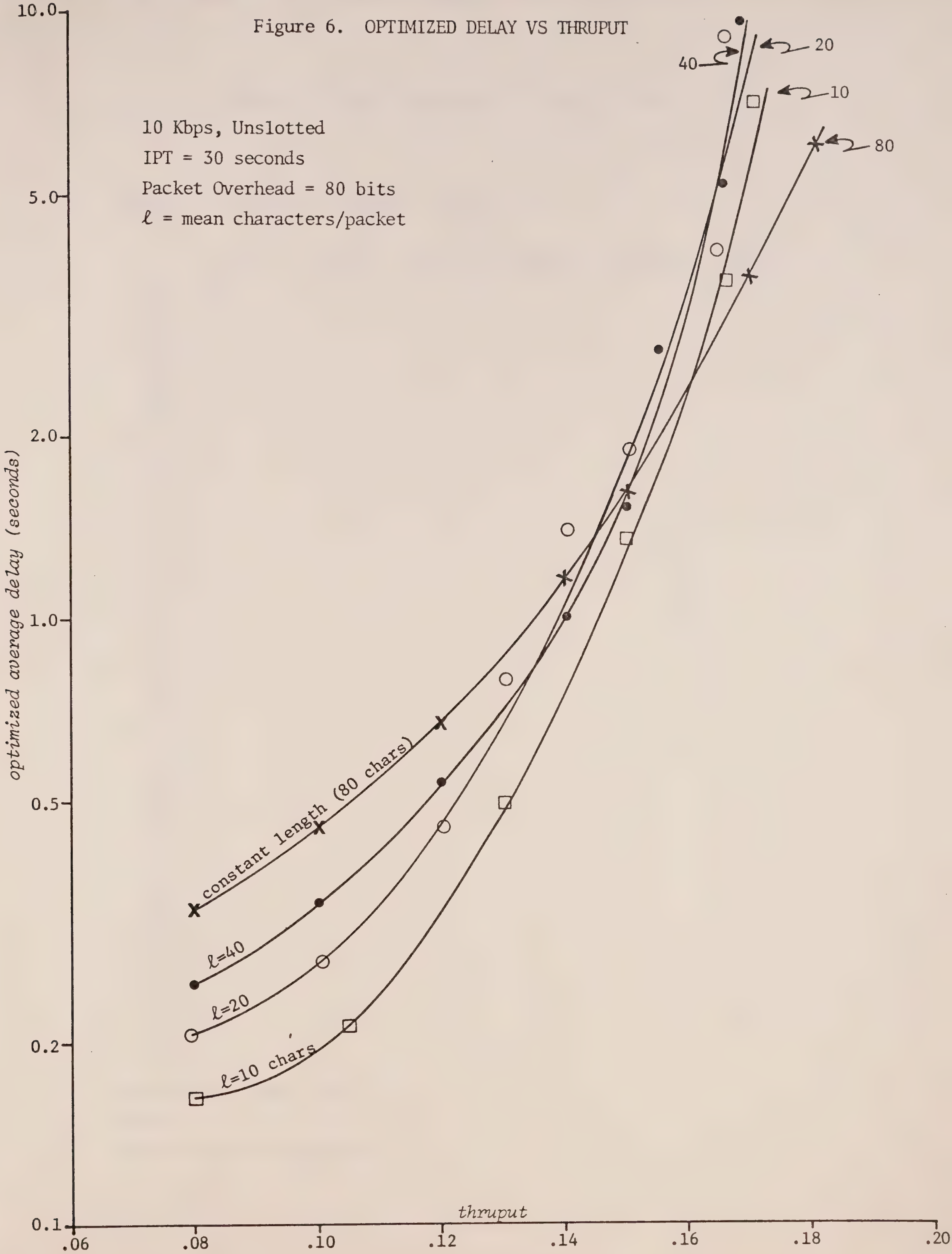
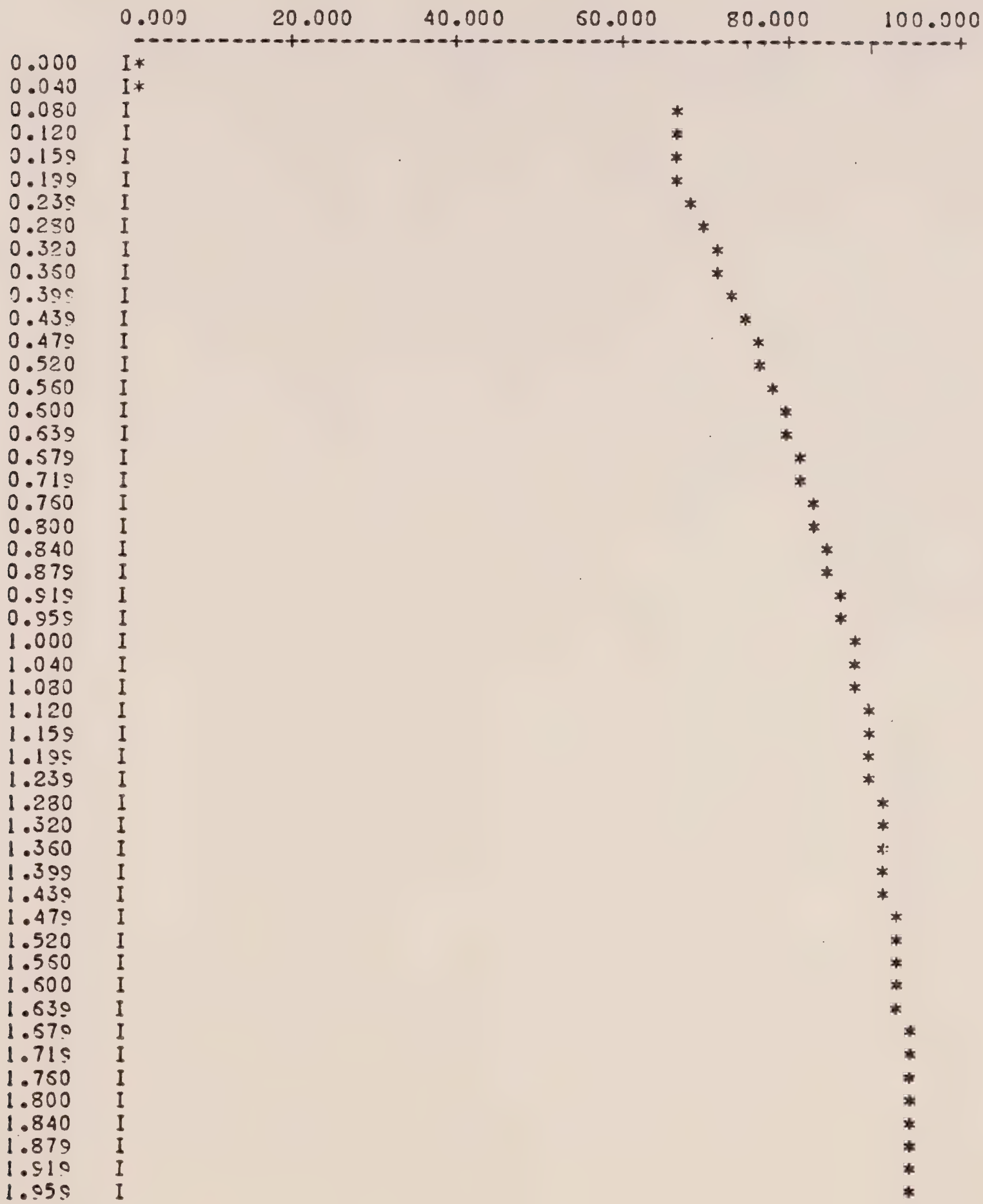


Figure 6. OPTIMIZED DELAY VS THRUPUT
10 Kbps, Unslotted
IPT = 30 seconds
Packet Overhead = 80 bits
ℓ = mean characters/packet
constant length (80 chars)
ℓ=40
ℓ=20
ℓ=10 chars
40
20
10
80
optimized average delay (seconds)
thruput
10.0
5.0
2.0
1.0
0.5
0.2
0.1
.06
.08
.10
.12
.14
.16
.18
.20

Figure 7. DELAY HISTOGRAM: ℓ = 10, N = 250

```
FREQ. & % OF UNDERFLOW = 0.000      0.000
FREQ. & % OF OVERFLOW = 288.000      0.052
```



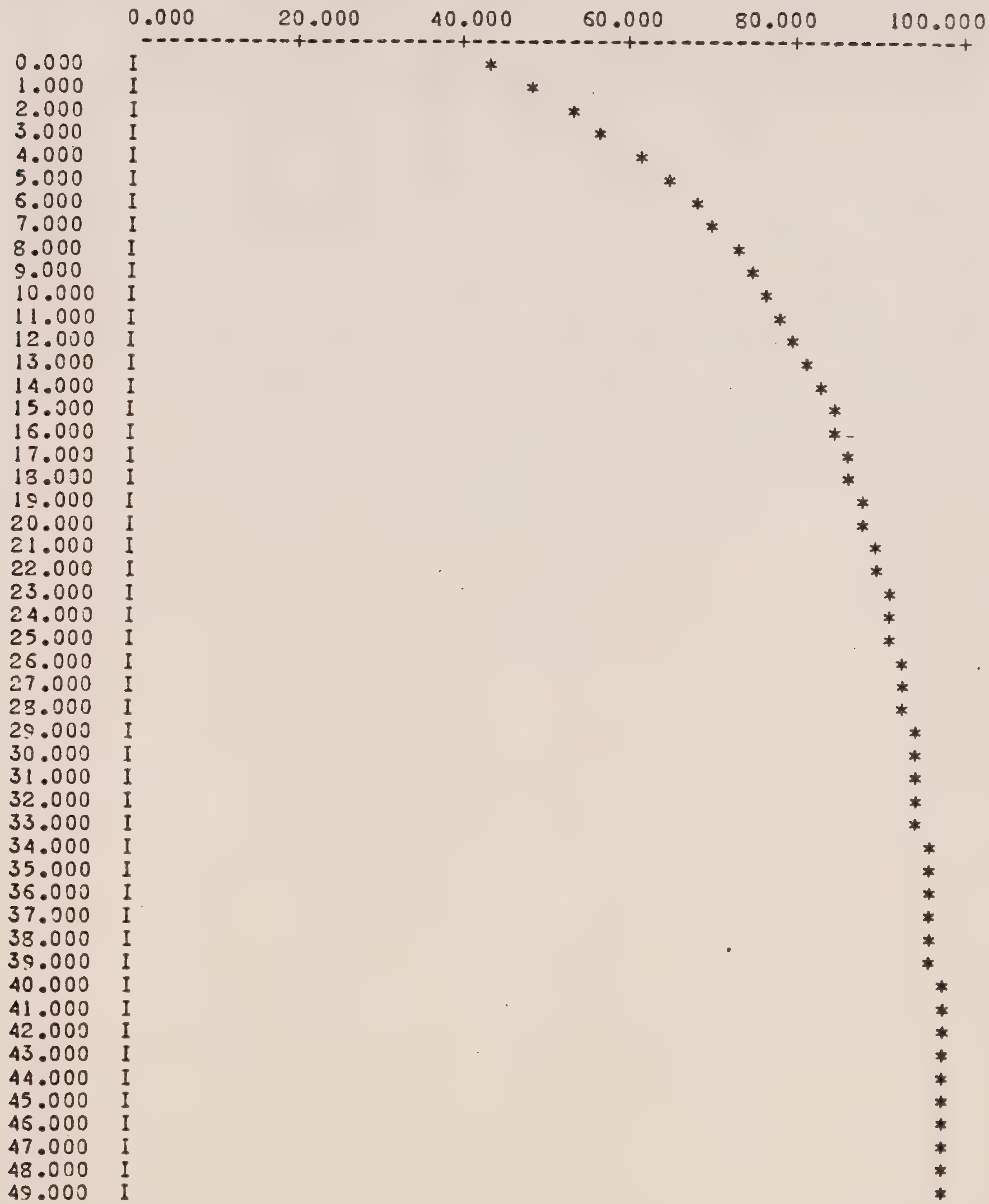

```
ISEED,USEED = 64A9   ,0001

RERUN? N

THIS IS THE END OF SIMULATION.
```

Figure 8. DELAY HISTOGRAM: $\ell = 10$, N = 400

```
FREQ. & % OF UNDERFLOW = 0.000      0.000
FREQ. & % OF OVERFLOW = 62.000      0.018
```



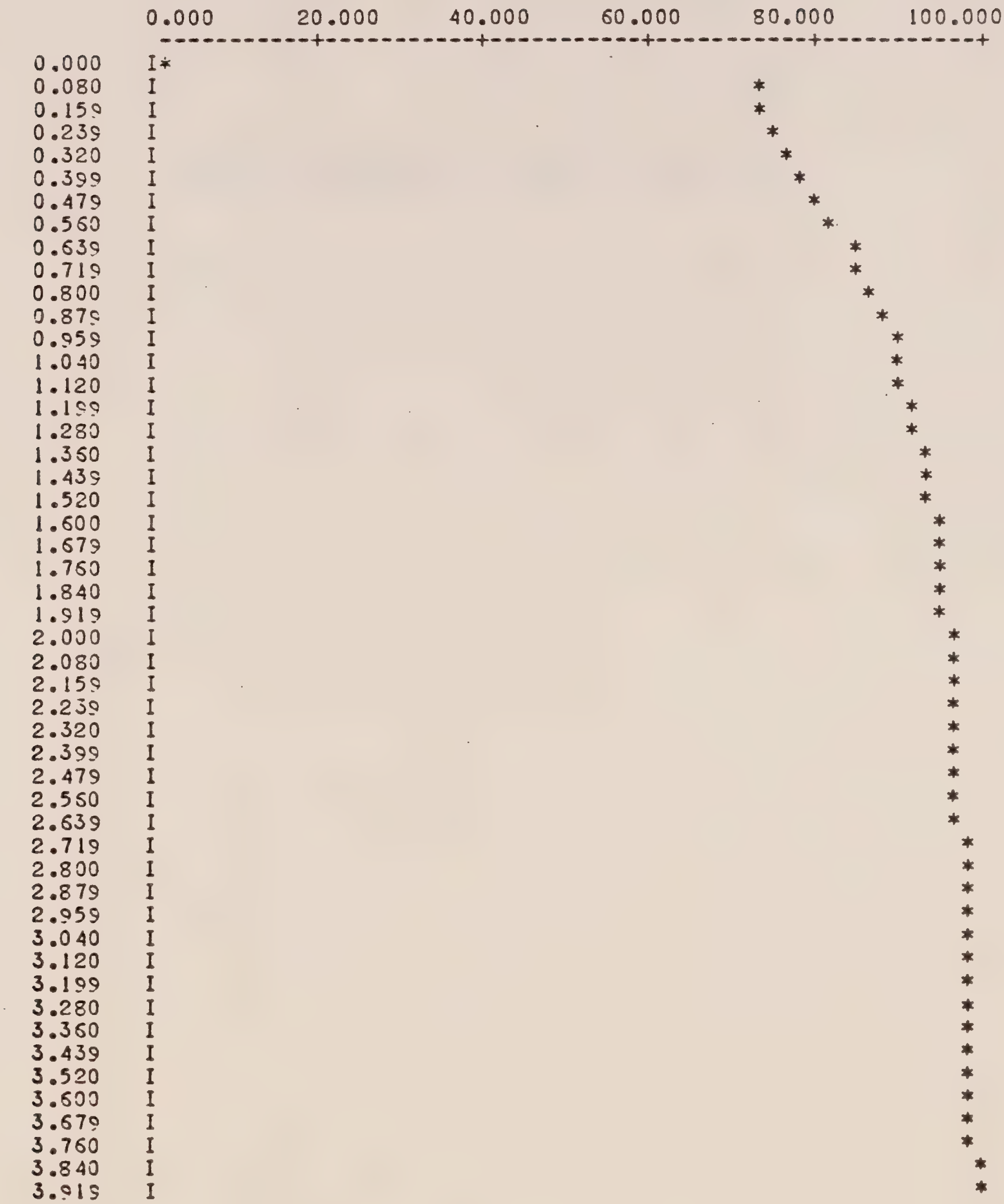

```
ISEED,USEED = 3773   ,0001

RERUN? N

THIS IS THE END OF SIMULATION.
```

Figure 9. DELAY HISTOGRAM: ℓ = 40, N = 100

```
FREQ. & % OF UNDERFLOW = 0.000      0.000
FREQ. & % OF OVERFLOW = 85.000      0.014
```




```
ISEED,USEED = 4958  ,0001

RERUN? N

THIS IS THE END OF SIMULATION.
```

Table I. COMPARISON OF DELAY HISTOGRAM PERCENTILES

VALUE OF PACKET DELAY (m=mean delay)	PERCENT OF PACKETS WITH GREATER DELAY		
	ℓ = 10		ℓ = 40
	S=.13	S=.17	S=.11
m	23%	27%	20%
2m	12%	15%	10%
3m	7%	8%	7%

Note: S ≡ thruput

ℓ ≡ mean characters/packet

5. RELATIVE PERFORMANCE VS ℓ

Note: All results in this section are for optimum values of R_e.

Using the results for constant-length 720 bit packets as a reference, the solid curve in Figure 10 shows the relative increase in number of users as a function of ℓ at a constant thruput of 0.16. The values were obtained from Figures 5 and 6. For comparison, the dashed curve in Figure 10 shows the calculated improvement L_R which would be obtained if constant length packets containing ℓ characters were used.

Figure 11 shows the maximum number of users which can use the 10 Kbps channel for a given ℓ without exceeding a given average delay constraint (where all users have a mean think-time of 30 seconds). The values were obtained from Figure 5. The relative increases for the 1.0 and 2.0-second curves correspond closely to those of Figure 10 (high thruputs). However, if the delay constraint is lowered to 0.5 seconds, more than 5 times as many users can be present for ℓ=10 than for the constant ℓ=80 (compared to an improvement factor of 4.1 in Figure 10). If the delay constraint is lowered to 0.2 seconds (the value chosen for ARPANET), more than 10 times as many users can be present for ℓ=10 than for the constant value of 80! Thus, while only about 15 users can use the channel with constant 80-byte packets, almost 200 users are allowed under the more realistic variable packet length traffic assumptions [2].

The small number of users just noted for 80-byte packets is of course due to the long packet transmission time (relative to the 0.2 second constraint) resulting from the 10 Kbps data rate (and our use of a 720-bit packet time for all acknowledgements). This implies the use of a higher data-rate channel if many users are expected to send 80-byte packets. However, an increase in data-rate does not in general guarantee a corresponding decrease in delay for a given channel loading, as will be shown in a subsequent report.

Figure 10. RELATIVE INCREASE IN NUMBER OF USERS AT S = 0.16

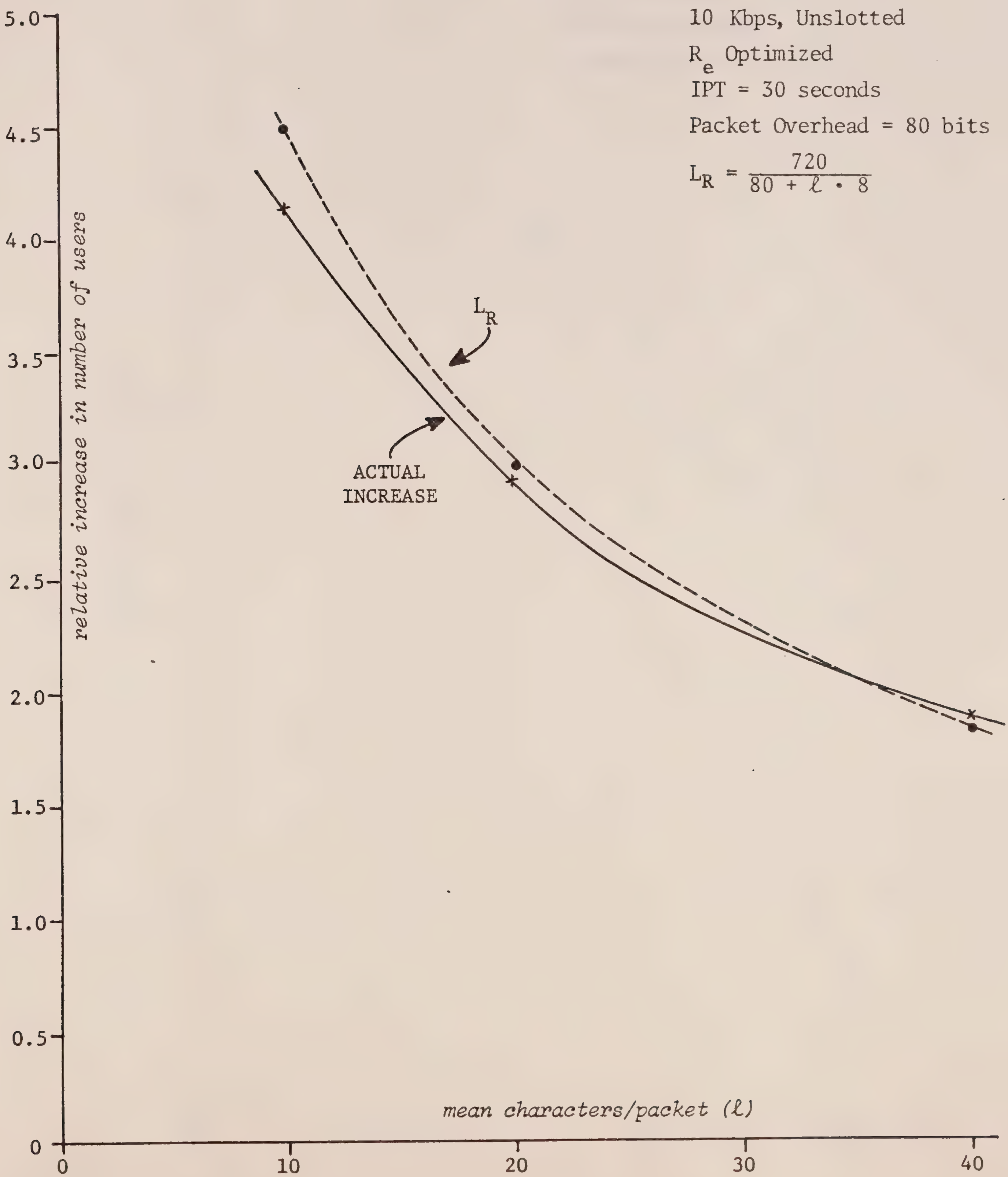
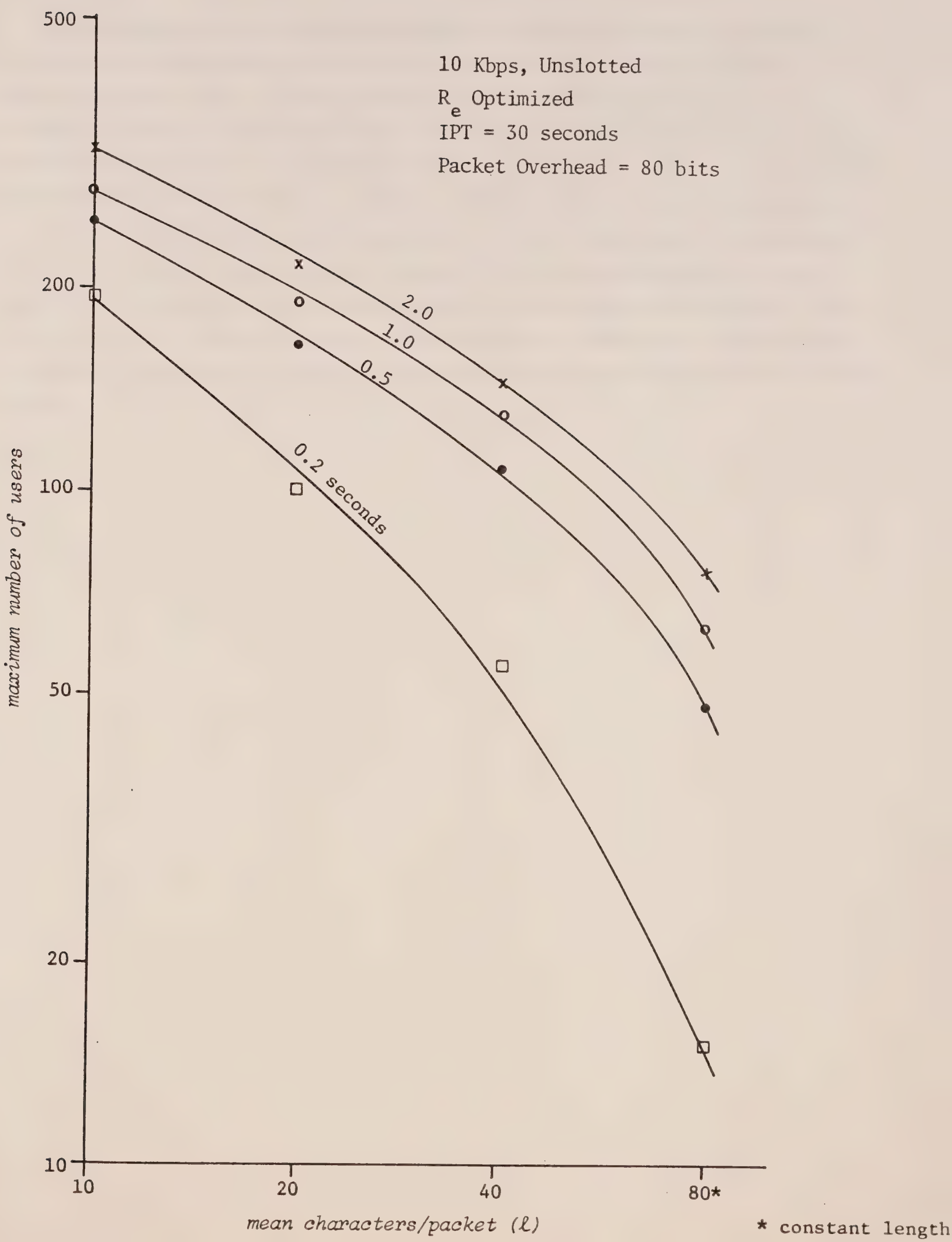


Figure 11. MAXIMUM NUMBER OF USERS VS PACKET LENGTH, CONSTANT DELAY



6. CONCLUSIONS

A large range of retransmission means was found necessary to optimize the unslotted channel over the full range of achievable thruput values, as shown in Figures 1 to 4. This implies a need to dynamically change the retransmission mean at all user nodes as average channel loading changes, if reasonable delays are to be achieved under light loading conditions while also minimizing delays and stability problems during periods of peak loading [3].

On the positive side, large gains were found in the number of allowable users when variable length packets are used with a mean comparable to that expected for interactive user traffic (about 10 characters per packet). For a constraint of 0.2 seconds average packet delay and a mean user think-time of 30 seconds, the number of users is increased from 15 to almost 200 in a 10 Kbps channel.

REFERENCES

[1] "SIMFAC Version II User's Guide," *ALOHA General Document CCG/G-74*, University of Hawaii, January 1975.

[2] JACKSON, P.E. and STUBBS, C.D.: "A Study of Multiaccess Computer Communications," *AFIPS Conference Proceedings, Spring Joint Computer Conference*, Vol. 34, 1969, pp. 491-504.

[3] LAM, SIMON S.: "Packet Switching in a Multi-Access Broadcast Channel with Application to Satellite Communication in a Computer Network," *Report UCLA-ENG-7429*, University of California, School of Engineering and Applied Science, April 1974.